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Prediction of Fatigue Cracking and Rutting in Asphalt Pavements by Small-Scale Centrifuge Models

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SYNOPSIS

This paper presents a summary of a study to investigate the feasibility of predicting fatigue cracking and rutting in full depth asphalt pavements by centrifuge modeling. This is accomplished by constructing a small-scale centrifuge model and measuring directly the resilient tensile strains at the bottom of asphalt layer and the accumulated permanent on the pavement surface under repeated loads. The purpose of using a centrifuge is to insure that the stresses and strains due to self weight are the same in the small-scale model as in the prototype pavement.

Model pavements in two different scales of 1:10 and 1:20 were constructed, using two different asphalt contents and compaction levels. It was found that the resilient deformations and strains measured in the 1:10 models checked well with those in the 1:20 models for all test combinations. Although the permanent deformations experienced a large range of variations, the average of the 1:10 models also checked reasonably with that of the 1:20 models.

INTRODUCTION

This report summarizes the results of a preliminary study on the feasibility of using small-scale centrifuge models for predicting the fatigue cracking and rutting in asphalt pavements. Although the technique of centrifuge testing is not new and has been used frequently in geotechnical engineering (Cheney, 1982), the concept has not been applied to pavement research anywhere in the world. This study was supported by the Strategic Highway Research Program as an IDEA (Innovation Deserving Exploratory Analysis) project.

The basic idea of centrifuge testing is to construct a small-scale pavement model similar to the prototype pavement structure and subject it to centrifugal forces, so that the stresses and strains due to self weight are the same as those in the prototype pavement. This model is thensubjected to repeated loads with the same stress levels as in the prototype pavement. The horizontal resilient tensile strains at the bottom of asphalt layer and the accumulated permanent deformations on the pavement surface under increasing load repetitions can be measured directly. The reason for measuring the resilient tensile strain rather than observing the fatigue cracking directly is due to the very long testing time required for fatigue cracking to occur. The models were tested to 10,000 repetitions but more than one million repetitions may be needed to induce fatigue cracking.

One method to check the validity of centrifuge testing is by applying the "modeling of models" concept. This concept implies that a small-scale model can be modeled by an even smaller model. The 1:20 model can be used to model the 1:10 model. All the deformations in the 1:20 model should be one half of those in the 1:10 model but the dimensionless tensile strains should be the same. In other words, no matter what scale factors are used, the same results should be obtained when scaled back to the prototype.

CENTRIFUGE FACILITY AND INSTRUMENTATION

Figure 1 is a schematic diagram showing the components of pavement and loading for both the prototype and small-scale models. The pavement is composed of a layer of sand asphalt, or fine mix, with a thickness of h_1 and a sand subgrade with a thickness of h_2 and is underlain by a rigid base. Loads are applied to the pavement through a circular disk with a diameter of D. The small-scale pavement can also be considered as infinite in areal extent because the distance from the load to the circumferential boundary is very large compared to the radius of the loaded area (Huang, 1969).

The loading consists of a repeated load of 80 psi and a static load of 10 psi.

PAVEMENT RESPONSES

Based om the Burmister's layered theory(Yoder and Witczak, 1975), the deformation, stress and strain at any point in a layered system can be expresses as

$$s = qF_s \qquad (1)$$

$$w = qDF_w \qquad (2)$$

in which s = stress of strain, q= average contact pressure or the totalload divided by the contact area, F_s= stress or strain factor

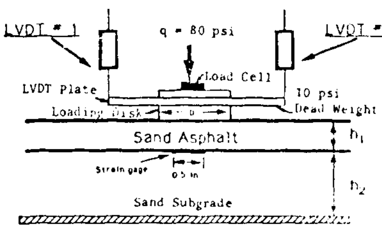

Figure 1 Schematic diagram of prototype pavement and small-scale models

or strain factor, w = deformation, D= diameter of loaded area, and F_w = deformation factor. Note that F_s and F_w depend on the dimensionless ratios, h_1/D and h_2/D, as well as the properties of the material in each layer. As long as the contact pressure, q, and the ratios, h_1/D and h_2/D, are the same, the stress and strain will be the same but the deformation will be proportional to the diameter of the loaded area, D. In other words, a small-scale model with a smaller loaded area can be used to simulate a prototype pavement with a larger loaded area if the other linear dimensions are reduced proportionally.

SCALE FACTORS

To verify the "modeling of models" concept, two different scale factors were used in this study. Table 1 shows the dimensions and weights of the prototype and the small scale models. The prototype pavement to be modeled is composed of 10 in. of asphalt over 30 in. of subgrade on top of a rigid base.

Type	Prototype	1:10 Model	1:20 Model
Loading Diameter, D (in.)	12	1.2	0.6
Asphalt thickness, h_1 (in.)	10	1.0	0.5
Subgrade Thickness, h_2 (in.)	30	3.0	1.5
Angular Velocity, T (rpm)	0	88	124
Weight of loading ram (lb)	9050	9.53	1.18
Weight of LVDT plate (lb)	1131	0.88	0.11

Table 1. Prototype versus Small-Scale Centrifuge Models

CENTRIFUGE

A centrifuge with a capacity of 6,000 g-lb was extensively modified to make it capable of testing small-scale models under both repeated and static loading. The facility is located in an isolated section of the Daniel V. Terrell Civil Engineering Research Laboratory. This laboratory houses a complete soil mechanics laboratory, a machine shop and the necessary instrumentation for the operation and maintenance of the centrifuge. As shown in Figure 2, the centrifuge consists of the following basic components:

1. Rotating arm and counterweight.
2. 2-HP electrical motor and gear reduction.
3. Structural frame to support the drive shaft connected to the rotating arm.
4. protective housing and wall of sand bags.
5. Slip ring assembly to pass the lead wires from the transducers in the test capsule to the signal conditioner.
6. Encoder to measure the angular velocity in rpm.
7. Test Capsule to house the small-scale model to which the repeated and static loads are applied.

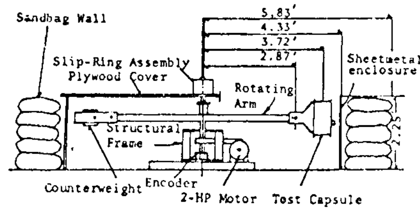

Figure 2 Major components of centrifuge

TEST CAPSULE

Aview of the test capsule mounted on the centrifuge arm is shown in Figure 3. Starting from the bottom, the capsule consists of lower base plate and plexiglass cylinder, pavement model,LVDT plate, capsule lid and loading device,

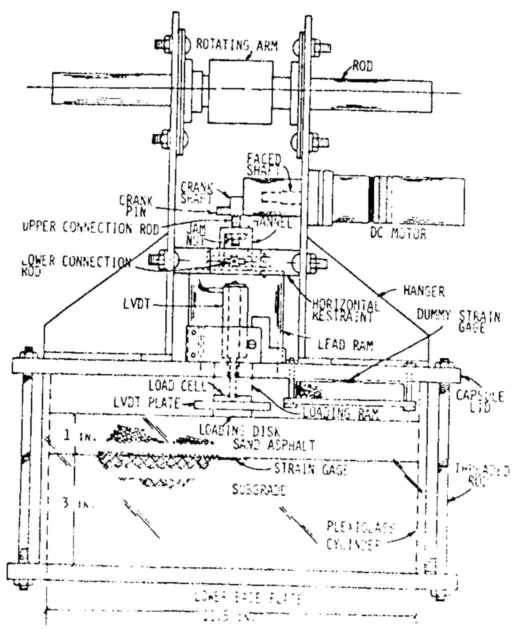

Figure 3. Schematic diagram of centrifuge capsule

LOADING DEVICE

A special loading device was designed and constructed to apply the repeate load to the model.(Roghani 1990)

Figure 4 shows the different loading waveforms which can be generated. The 0.1 sec loading and 0.9 sec rest waveform has been used most widely to simulate the traffic. However, in this research the 0.45 sec loading and 0.55 sec rest waveform was used because it gave consistent results.

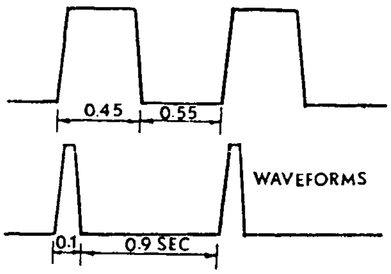

Figure 4 different waveforms of repeated load

DATA AQUISITION SYSTEME

An IBM PC was used together with Labmaster data acquisition boards to perform the required data acquisition and reduction. Figure 5 shows schematically how different parts of centrifuge apparatus are interconnected.

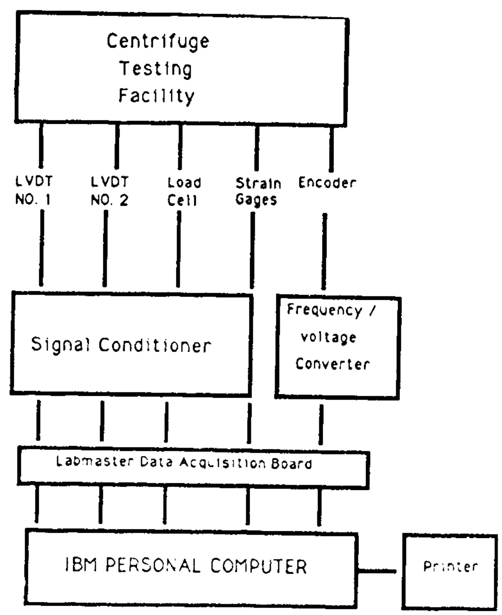

Figure 5. Data aquisition system for centrifuge facility

MATERIALS AND FABRICATION OF ASPHALT SPECIMENS

Materials

The materials used in this study include asphalt mixture for fabricating the centrifuge and cylindrical specimens and river sand for constructing the subgrade of small-scale models.

ASPHALT MIXTURES

The asphalt mixture used for the small-scale model is a fine mix containing asphalt contents of 8.7% and 7%. The asphalt cement used for all mixes was an AC-20 obtained from the Ashland Oil Company, Ashland, Kentucky. (Roghani, 1990)

SAND

The sand used for the subgrade in the small-scale pavement models was a uniformly graded, dry Boonesboro river sand. Figure 6 shows the gradation of the sand.

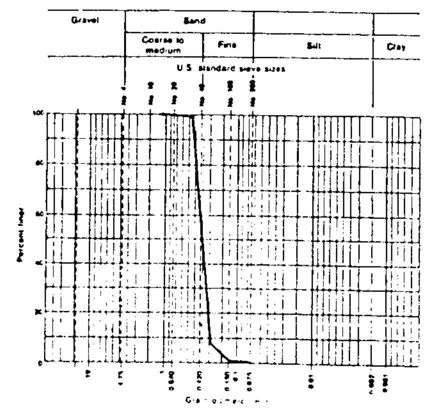

Figure 6 Grain size curve of sand

Centrifuge Specimen

The centrifuge asphalt specimens were 11.5 in. in diameter and approximately 1 in. thick for the 1:10 model and 0.5 in. thick for the 1:20 model. Due to the thin specimens used, only the fine mixture was used to fabricate the centrifuge specimens.

PREPARATION, TESTING AND ANALYSIS OF CENTRIFUGE MODELS

The preparation of small -scale models include the construction of sand subgrade and the installation of centrifuge asphalt specimen on the top of subgrade.

Hereafter, the repeated loads applied in the centrifuge test on the 1:10 model is refered to as the 10g test, while that on the 1:20 model as the 20g test.

The data obtained from the repeated load tests were the load magnitudes, the resilient strains at the bottom of asphalt layer , the resilient deformations and the permanent deformations on the surface. These data were recorded at 1, 10, 100, 1000, 4000, and 10000 repetitions. (Roghani, 1990)

RESULTS

Comparision Between 10g and 20g repeated load tests

The most important part of this research is to verify the "modeling of models" concept by comparing the 1:10 and 1:20 models. A comparison of the overall averages between 10g and 20g tests is as follows:

Resilient Strains

The resilient strain at the bottom of asphalt layer causes the fatigue cracking of the asphalt mixture and is an important factor for pavement design. Figure 7 shows the resilient strains for all test combination. The letter O implies an 1 inch asphalt specimen for the 10g test, while the letter H implies a half inch specimen for the 20g test. The first four set of bars compare 10g and 20g tests for each pair of specimens with thw same asphalt content and compaction level, while the last three sets of bars show the average values. Although emphasis is placed on the comparison between 10g and 20g tests, comparisons between asphalt contents of 8.7 versus 7% and compaction levels of 200 versus 300 kips can also be easily maid from the average on the right side of the figure. The figure shows that the 10g tests check well with the 20g tests and that the two asphalt contents and two levels of compaction have very small effects on resilient strains.

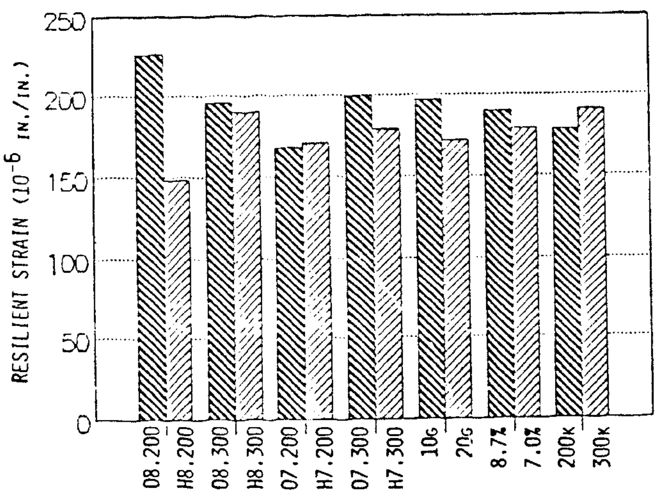

Figure 7. Comparison of resilient strains between 10g and 20g tests.

Resilient Deformations

Figure 8 shows the resilient deformations on the pavement surface for all test combinations. The resilient deformation is important because the permanent deformation is proportional to the resilient deformation. To determine the permanent deformation, a knowledge of resilient deformation is required. The figure also shows that the 10g and 20g tests check very well. The resilient deformations are about the same for the two compaction levels but asphalt content of 8.7% has greater resilient deformations than that of 7%.

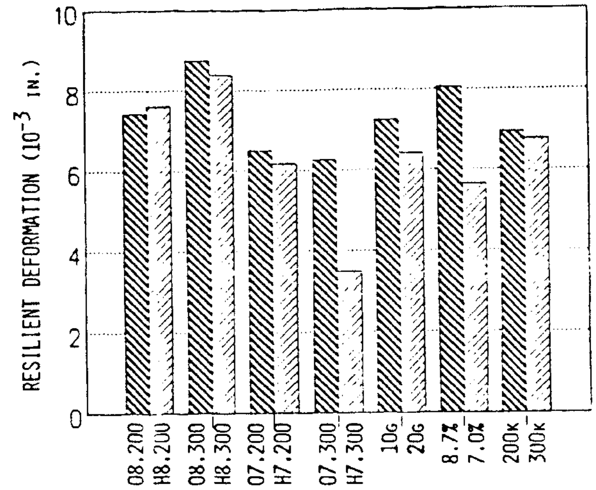

Figure 8. Comparison of resilient deformations between 10g and 20g tests.

Permanent Deformation

Figure 9 shows the permanent deformation on the pavement surface. The four horizontal lines in each bar indicate the permanent deformations at 1, 10, 100 and 1,000 repetitions, respectively. The top of the bar indicates the permanent deformation at 10,000 repetitions. In the figure, only the average for the 10g and 20g test is shown. It can be seen that permanent deformations have a large range of variations, particularly at the later part of the test when the number of repetitions are large. Inspite of the large variability, the average permanent deformations between the 10g and 20g test also check quite well.

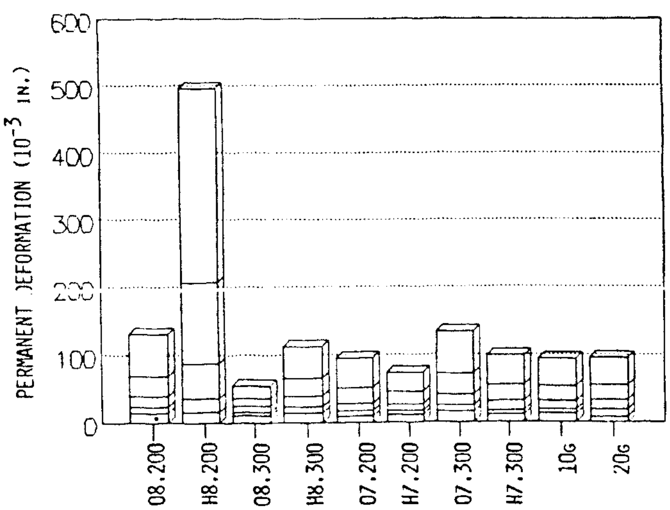

Figure 9. Comparison of permanent deformations between 10g and 20g tests

CONCLUSIONS

The main objective of this research was to investigate the possibility of predicting fatigue cracking and rutting in full depth asphalt pavements by centrifuge modeling. The major conclusion of this research is that centrifuge models can be used to predict pavement distresses and that the results obtained from the models check reasonably well.

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